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Request for grant of a patent

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1. Your reference — P3185 GB PRO

2. Patent application number *(The Patent Office will fill this part in)* — 0321918.5 — 19 SEP 2003

3. Full name, address and postcode of the or of each applicant *(underline all surnames)* — AOTI OPERATING COMPANY, INC
131 NW HAWTHORNE AVENUE
SUITE 207
BEND, OREGON 97701, US

Patents ADP number *(if you know it)* — 8113808002

If the applicant is a corporate body, give the country/state of its incorporation — DELAWARE, USA

4. Title of the invention — FOCUSING SYSTEM AND METHOD

5. Name of your agent *(if you have one)* — NOVAGRAAF PATENTS LIMITED

"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)* — THE CRESCENT
54 BLOSSOM STREET
YORK
YO24 1AP

Patents ADP number *(if you know it)* — 08299166001

6. Priority: Complete this section if you are declaring priority from one or more earlier patent applications, filed in the last 12 months.

Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*

7. Divisionals, etc: Complete this section only if this application is a divisional application or resulted from an entitlement dispute (see note f)

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8. Is a Patents Form 7/77 (Statement of inventorship and of right to grant of a patent) required in support of this request?
Answer YES if:
a) any applicant named in part 3 is not an inventor, or
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YES

9. Accompanying documents: A patent application must include a description of the invention. Not counting duplicates, please enter the number of pages of each item accompanying this form:

Continuation sheets of this form	
Description	12
Claim(s)	
Abstract	
Drawing(s)	1 + 1

10. If you are also filing any of the following, state how many against each item.

Priority documents	
Translations of priority documents	
Statement of inventorship and right to grant of a patent (Patents Form 7/77)	
Request for a preliminary examination and search (Patents Form 9/77)	
Request for a substantive examination (Patents Form 10/77)	
Any other documents (please specify)	

11. I/We request the grant of a patent on the basis of this application.

Signature(s) NOVAGRAAF PATENTS LIMITED Date 18/9/2003

12. Name, daytime telephone number and e-mail address, if any, of person to contact in the United Kingdom PETER WILSON (DR) 01904 610586

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Focusing System and Method

The invention relates to a focusing system and method, in particular to an automatic focusing system and method for focussing on a generally planar object in bright field microscopy, for example as used for examining silicon or other semiconductor wafers for the purpose of process control, and in particular for overlay metrology.

Automatic focus of an optical system requires the acquisition of information about the relative position of the object and the optical system. In many instances, the object approximates to a plane reflective surface, and the auto-focus will project a light beam onto the object and use the zero-order reflection from the object to determine the object distance.

The disadvantages of such a system are:

1) that surface detail in the object will affect the zero-order reflection and in some implementations will result in false readings;
2) when the object has topography, focus data will be taken from the best approximation to a plane and the ideal focus may be offset from this by an unknown distance;
3) that the light beam used for focus investigation may not have the same chromatic properties as the light which is used by the optical system when it is performing its intended task.

The present invention may best be described in the context of its application with a bright-field microscope as used for examining silicon wafers for the purpose of process control. A particularly preferred application of the invention is for measurement of focus information in overlay metrology in which the focal conditions under which the data are gathered have a

substantial impact on the quality of the data and this example is discussed in detail herein. Potentially however, the present invention could be used for any optical system in which there is a spatially-concentrated light-source.

In overlay metrology, light is injected into the top focal plane of a microscope objective to illuminate the object. Light reflected from that object is collected by the same objective and directed by means of a beam-splitter through an optical system to an imaging system which forms an image of the object. Typically this will compromise a ccd camera. The object consists of a pair of marks produced by photolithography on a silicon wafer. Overlay metrology is the process whereby the relative positions of the two marks are measured. Historically, these marks have tended to be marks with four-way rotational symmetry which are positioned so that they are nominally concentric. One mark is larger than the other so that the two marks may easily be distinguished. They are referred to as the inner mark and the outer mark. Overlay marks generally have straight edges.

For the purpose of discussions herein, light used for gathering focus data will be referred to as the focus beam and light which is used when the optical system is performing its intended task (e.g. overlay metrology) will be referred to as the metrology beam.

One method by which the correct focal distance for an object may be determined is to gradually change the object distance while continuously gathering data from the image formed by the optical system. If there is a well-defined criterion by which the "best focus" position can be judged (e.g. maximum spatial frequency content of the image, maximum intensity gradient, etc.) then the data collected as the object distance varies may be analysed to determine at which focal distance the defined criterion is best

complied with. Following this, the focus distance may be set to the identified best focus condition and the optical system can be used for metrology. Alternatively, if sufficient data were acquired during the through-focus scan, those data which were acquired in the out-of-focus condition may be discarded while those that were gathered at the in-focus condition will be used for metrology.

This methodology requires that a lot of data are acquired and analysed and is inevitably slow as time is taken up gathering data which are later discarded. To avoid this, many attempts have been made to develop auto-focus systems and auto-focus methods in which focus data may be acquired much more rapidly.

In many auto-focus systems, light beams are injected into the optical system by means of a beam-splitter. These injected beams will emerge from the objective, reflect from the surface of the object and return to the optical system. The injected beams have some character which may be measured in the returning beam and which will be modified by a change in the distance of the object.

These beam-modification methods can give focus information within a much shorter time interval. Systems employing this principle include laser-spot focus systems, twin aperture measurement systems and astigmatic beam systems. Such auto-focus systems may work well in a range of conditions, but are subject to a number of practical limitations.

First, these systems generally assume that the object is a mirror normal to the optical axis. Deviations from this ideal situation (topography of the sample, reflectance variation of the sample, etc.) tend to cause degradation of the focus

information that is obtained, as they change the character of the light beam that is being measured. (There are many situations in which this degradation is not present or is negligible, and some of these auto-focus systems work very well within a limited context.)

Second, the focus beam may be very limited in the wavelengths that it can use, e.g. a laser spot focus system will usually be limited to a single wavelength. The light in the metrology beam may be from a broad band source. In any system in which chromatic aberration had not been perfectly eliminated (i.e. any refractive optical system) there would be some offset between the best focus determined using the focus beam and the focus required by the metrology beam. As there may be some chromatic filtration of the metrology beam by the object (e.g. thin-film filtration on the surface of a silicon wafer) the offset may vary from sample to sample and may not be known.

It would therefore be advantageous to use light with the same chromatic character for the focus beam as for the metrology beam.

It is an object of the present invention to mitigate some or all of the above disadvantages of prior art auto-focus systems and methods.

It is a particular object of the present invention to provide an auto-focus system and method in which the data required to determine an optimal focus point are acquired more rapidly and/or the collection of ultimately redundant focus data is minimised.

It is a particular object of the present invention to provide an auto-focus system and method which can use light with the same chromatic character for the focus beam as for the main beam used for observing the object and/ or for

metrology, in particular enabling the use of a broad band light source and/or enabling the use of the same light source for a focusing and an observational or metrology step.

The invention relates to focusing systems on microscopes having a light source, an objective lens or lens system, a means to direct incident light through the objective lens or lens system to be reflected by the object, an aperture to limit the spatial extent of the incident light and serve as an illumination pupil, a means to direct at least some of the reflected light to an imaging system, and an imaging system to image the reflected light so directed.

In accordance with the invention in its broadest aspect, a method of automatically focusing such a system comprises the steps of directing a beam of light from a light source through an objective of a microscope system to an object whence light is reflected from the surface thereof; collecting at least some of the light reflected thereby and directing the same to an imaging system, wherein the incident beam of light is limited in spatial extent by imaging an aperture to form an illumination pupil, the centroid of illumination of the illumination pupil is aligned with the incident optical axis of the instrument, and reflected light is projected to the imaging system comprising at least one pair of images from eccentric sections of an imaging pupil displaced from the optical axis in opposite directions, and wherein the separation of the images thereby produced is determined to provide an indication of the object distance.

In accordance with the invention a novel focus system and method are described in which focus information is gathered during a focusing step about the object distance by observation of those details of the object upon which it

is desired to focus during a subsequent observational (for example metrology) step using the light source that is used by the optical system when it is performing its intended observational task.

The method provides a very rapid method of determining the distance of an object and thus can be employed in determining an optimal focus position. It makes use of the aperture provided in objective path to limit the spatial extent of the incident light beam, and of measurements related to the illumination pupil formed thereby. This is discussed in detail below.

The illumination beam which is injected into the top focal plane of the objective in an overlay-metrology tool or similar application is limited in its spatial extent. The boundary of this spot of light is formed by imaging an aperture. The image of this aperture in the top focal plane of the objective is often referred to as the illumination pupil, which term is used herein.

Anyone familiar with optical microscopy will know that if the illumination pupil in an optical microscope is not properly aligned then the image of an object will appear to wander across the field of view as the object distance changes. Only by accurate centration of the illumination pupil can the image be made to remain stationary with changes of object distance. This statement should be refined slightly in the case where the illumination pupil is not a perfect circle or is not uniformly illuminated. Under these circumstances, the fundamental required condition is that the centroid of illumination is placed on the optical axis. However, in the preferred case where the pupil is circular and evenly illuminated this will equate to a requirement that the pupil is centred on the optical axis.

The reference for perfect alignment is the axis formed by the imaging system. If the imaging pupil is off axis, compared to the axis defined by the illumination pupil a similar effect will occur.

The essence of the invention is to make images of the object using eccentric sections of the imaging pupil and to project them onto a single imaging means for example a single detector array. At least two such images are collected for projection to different imaging areas but preferably relatively adjacent areas on a single imaging system. If the sections of the imaging pupil are displaced from the optical axis in opposite directions, then the separate images will move in opposite directions. Calculation of the separation of the images will then provide a measurement of the object distance.

Given that the object may have topography, it may be desirable to acquire different focus information for different parts of the object, e.g. the focus information for the outer mark may be collected separately to that for the inner mark. This information may be useful for applying corrections to the metrology.

Thus, in a preferred embodiment, the method compromises successively repeating the above outlined method steps to obtain separate pairs of images from eccentric sections of the imaging pupil, measurements of the separation of the successive pairs of images being used, for example as part of iterative process, to improve the accuracy of the focusing information and/or to obtain focusing information varying spatially across an object, particularly to accommodate a degree of deviation from planarity.

The light that is used for the focus investigation may have the same chromatic content as the light which is used for metrology. Preferably it will be from the

same light source. The system will therefore not require calibration to remove chromatically induced offsets.

A separate optical system and imaging system can be used to investigate the focus condition. This will require a beam-splitter in order to extract light reflected from the sample. In this separate focus optical system, an image of the pupil of the primary imaging system is formed using a relay lens. This pupil may then be split up by introduction of suitable image separation optics, for example comprising a series of apertures and subsequent steering optics, so adapted that the separate sections of pupil will form separate images on the imaging means, for example of a detector array, provided as part of the focus optical system and imaging system.

In this case, the focus optical system is separate from the primary observational optical system which is used to image the object, obtain metrology data or other measured data therefrom, etc once the focus has been determined. Such primary observational optical system will again compromise a suitable arrangement of optical elements to direct reflected light from the object to an observational imaging means, again preferably compromising a detector array. In the alternative, a single optical system with a common imaging means can be used first to investigate the focus condition and subsequently to conduct observation and/or measurement of the object.

In the preferred embodiment discussed herein (called CCF for Camera Correlation Focus), the simple device of a dihedral mirror has been used to serve as the image separation optics. This simultaneously splits the pupil into two and redirects the light from the two halves to different sections of the ccd array provided as part of the focus optical system. This is by way of example

only and it is not difficult to think of other systems to split the pupil though this is a particularly simple method.

In the focus optics detection means are required at least to determine the displacement of two images. The images will be very similar in many respects. It is therefore reasonable to use pattern recognition/correlation techniques (e.g. to store a portion of the first image and to determine where in the second image there is an object which correlates with the stored portion.) Using the position of the first portion of image as a starting point and knowing the direction of the displacement of illumination, the area of the second image that needs to be investigated will be very small and require little processing.

In the case where there are straight edges, as in the overlay mark, the misalignment of the pupil sections may be made in a direction which is orthogonal to one of the straight edges. The relative positions of the images may be calculated by measuring the relative positions of the edges in the two different images.

A field stop is preferably provided in the illumination beam from the light source. The field stop is intended to ensure that there is no overlap of the two images formed when the system is being used to investigate the focus condition. The size of the field stop is preferably selected with this intention in mind, but to ensure that this does not effect the image observed during the observation phase of operation. This can be achieved because the image of this stop is likely to be larger than the field of view during the observational phase which is carried out at high magnification, but effective as a limit stop at the lower magnification which might typically be used for the focus investigation.

In accordance with the invention a further aspect, a microscope auto-focus system is provided for the implementation of the foregoing method, and a microscope is provided equipped with such a system.

Specifically, such a system for a microscope comprises a light source, an objective lens system, a means to direct incident light through the objective lens to be reflected by the object, an aperture to limit the spatial extent of the incident light and serve as an illumination pupil with a centroid of illumination on the optical axis, a means to direct reflected light from the object to an imaging system, and an imaging system, and the system further comprises a means to project reflected light to the imaging system comprising at least one pair of images from eccentric sections of an imaging pupil displaced from the optical axis in opposite directions, and a means to measure the separation of the images thereby produced to provide an indication of the object distance.

Preferably a first optical and imaging system is provided for a focus image to be used to determine optimal focus position in a first focusing step, and a second optical and imaging system is provided for an observational image to be used in a subsequent observational (for example metrology) step, with a beam splitter and/ or selective optics disposed therebetween to divert reflected light from an object selectively to either imaging system and/ or partially to both.

Further preferred features of the system will be understood by analogy with reference to the description of preferred features of the method.

The invention will now be described by way of example only with reference to Figures 1 of the accompanying drawings, illustrating an example focusing system in accordance with the invention.

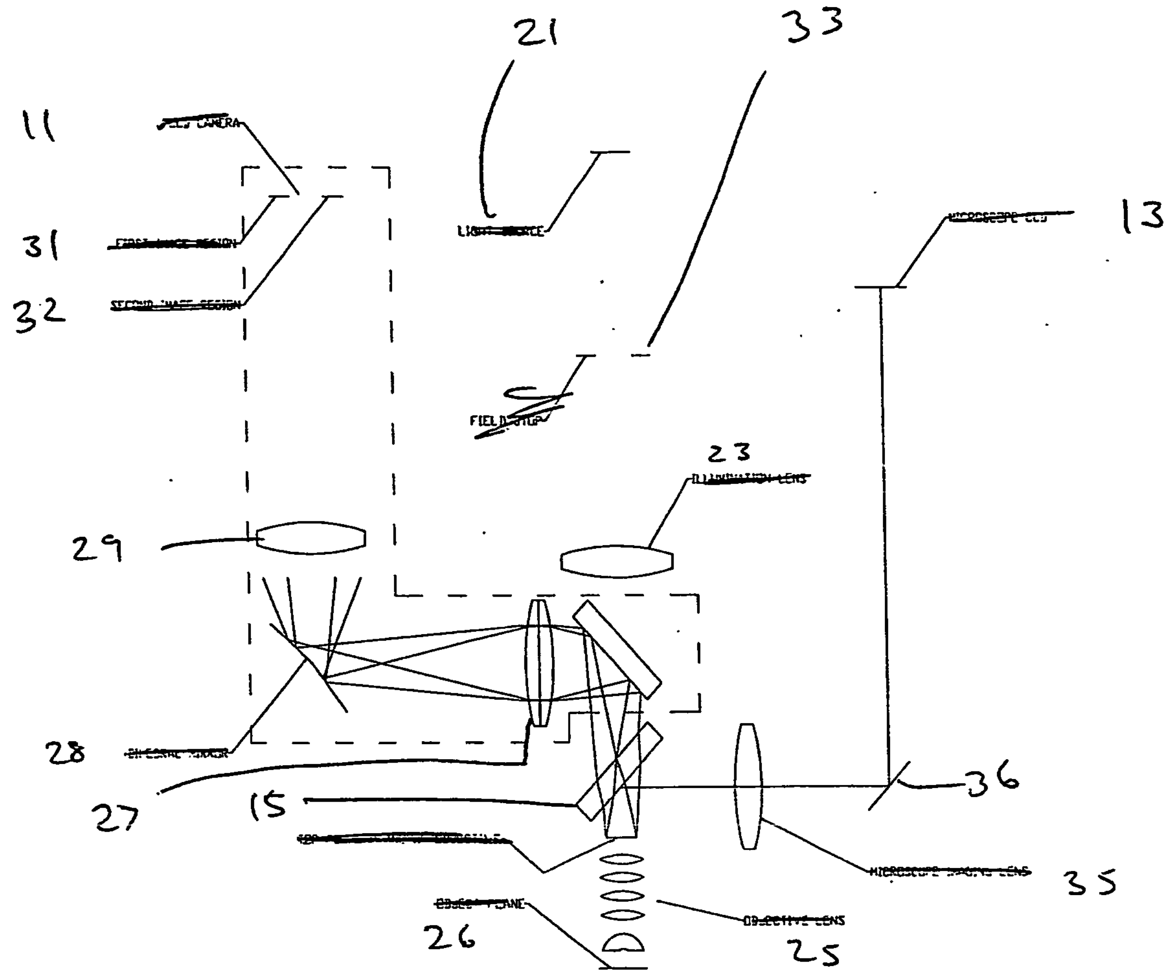
The system illustrated in Figure 1 is set up as a tool suitable for overlay metrology but will illustrate the general principles of the invention with more widespread applicability. The system illustrated in Figure 1 includes separate optical systems to collect the imaging information to investigate the focus condition, and to collect the imaging information by metrology. These compromise the focus ccd camera 11 and the microscope ccd 13. Beam-splitting 15 extracts light reflected from the assembly to serve both these imaging systems.

A light source 21 directs a beam of light along the light path represented by the dotted line through an illumination lens 23 and objective lens 25 onto an object at the object plane 26. Reflected light passes through the beam-splitter 15. During an investigation of the focus condition we are concerned with light directed back towards the focus ccd camera 11. The reflected light is directed via a first imaging lens 27 onto a dihedral mirror 28. It is through the dihedral mirror that the essential feature of the invention is enabled. The dihedral mirror simultaneously splits the illumination pupil into two and redirects the light via the second imaging lens 29 to different sections of the focus ccd 11, comprising the first imaging region 31 and the second imaging region 32.

In order that there is no overlap of the two images on the focus camera, a field stop 33 is preferably included in the illumination beam of the microscope. This does not affect the image observed in the metrology channel because the image of this stop is larger than the field of view in the metrology channel but the focus camera system 11 works at lower magnification.

A further advantage of this stop is that the image of the stop also moves with object distance in the same way that the image of the object moves. The rate of movement of the image of the field stop is twice that of the rate of movement of the object. This provides a means to focus the system when there is no object detail visible.

Once the focus condition has been investigated, the metrology camera ccd 13 is used for metrology observations. Light is directed thereat via the beam splitter 15 and microscope imaging lens 35 and mirror 36.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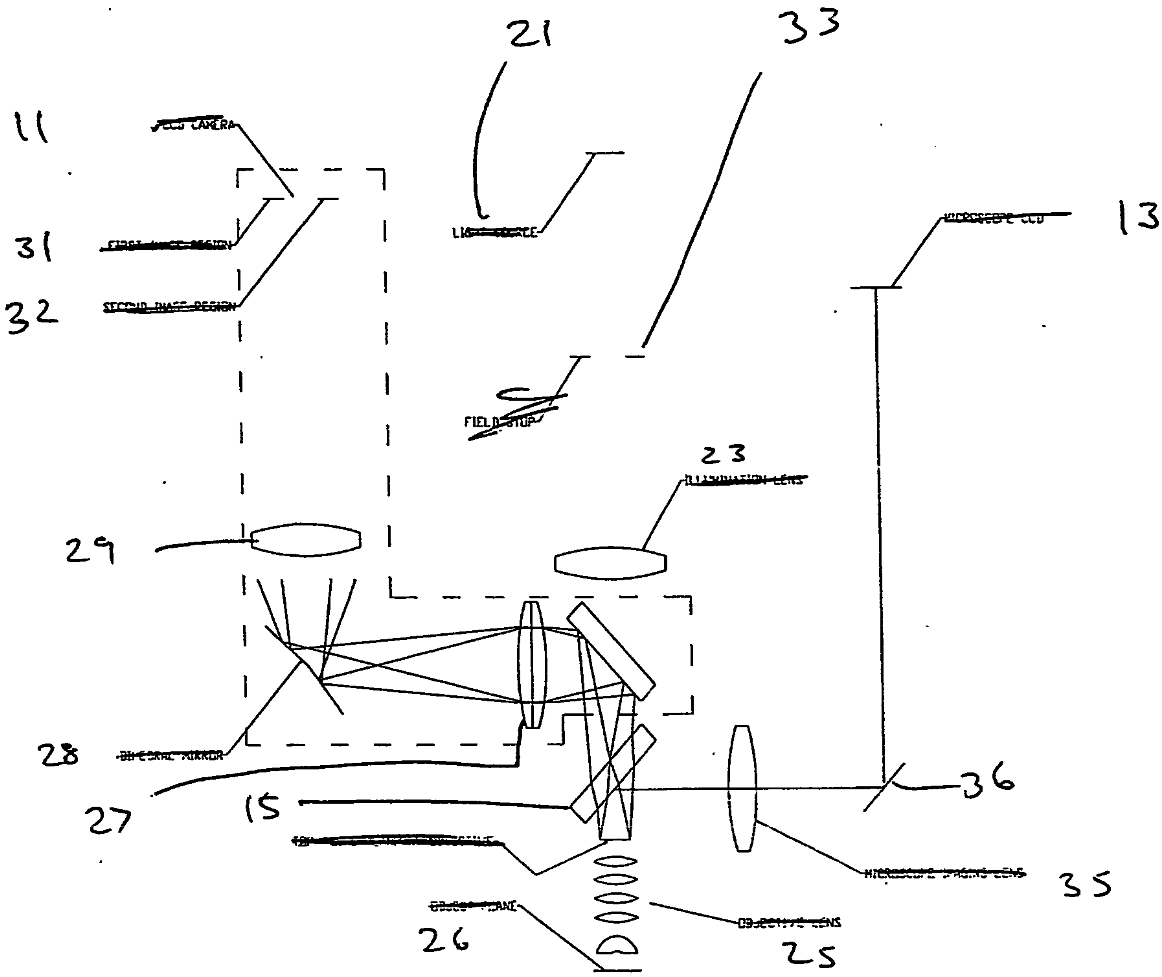

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